International Journal on Recent and Innovation Trends in Computing and Communication
ISSN: 2321-8169 Volume: 12 Issue: 2
***Article Received:** 25 November 2023 **Revised:** 12 December 2023 **Accepted:** 30 January 2024*

Mobile-Based Monitoring System Framework for Smart Hydroponics Lettuce Farming

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Abstract—Hydroponics farming is popular all over the world because it sustains many people who suffer from hunger and who don't have a lot of space or land that can be planted. The focus of this study is to provide material and design for innovative smart hydroponics farming that involves growing a lettuce plant using IoT devices, sensors, and Node-Red. Conducting this study is critical to the research because different components need to be identified first, as well as features for mobile devices connected to the IoT devices. The aim of this study is to design an IoT-based system that constantly monitors the water level, temperature, and humidity of the hydroponic lettuce crop. To fulfill the aim of the study, the researchers provide material and design for how it works, methodology for the hardware of the system, and a design thinking process to address complex problems and come up with unique solutions that emphasize innovation. As a result, the study can collect data from the different sensors. The readings of the sensors can be accessed through the Node-red Dashboard, viewable on mobile devices. Additionally, the researchers suggested exploring more about Node-Red and other possible uses of it in the IoT.

Keywords-green house; hydroponics; node-red; sensors; vertical farming

I. INTRODUCTION

Vertical farming is a sustainable and space-efficient kind of agriculture that uses modern techniques such as hydroponics, aquaponics, and aeroponics to produce crops without soil [1]. This strategy, particularly in highly populated metropolitan areas, boosts crop output per square foot and enables year-round production by controlling temperature, humidity, and illumination. The combination of automation and data-driven technology improves efficiency and production even further. Sensors, robots, and artificial intelligence systems monitor plant health, nutrient levels, and ambient variables in real time, enabling farmers to make data-driven decisions.

Let's start with a brief overview of vertical farming to better grasp the many classifications. Aeroponics is a farming method that blends aeroponics principles with vertical growth techniques to maximize efficiency and save space [2]. This technology enables the vertical stacking of growing beds or towers, which optimizes land utilization and agricultural productivity. Vertical aeroponic farming conserves water and nutrients, making it one of the most resource-efficient food production systems [3]. It also gives farmers more control over environmental conditions, allowing them to grow crops all year. The use of automation and modern technology improves the efficiency and production of vertical aeroponic farming, with sensors, monitoring systems, and robotic systems aiding in duties like planting, harvesting, and maintenance.

However, aquaponics is a sustainable and efficient food production technology that employs a closed-loop ecosystem of fish and plants [4]. This approach maximizes land utilization by stacking growing beds or towers in controlled indoor conditions, making it excellent for urban areas. Vertical aquaponic systems provide year-round production while controlling environmental factors such as temperature, humidity, and illumination. They also increase resource efficiency by optimizing water and fertilizer consumption in the closed-loop environment [5]. Automation and technology enable farmers to monitor water quality, fish health, and plant development in real time, assuring optimum agricultural yields while decreasing waste and operational expenses [6].

Finally, hydroponics is a sustainable method of agricultural production that uses limited area while preserving resources [7]. Traditionally, farming has been horizontal, but with urbanization and rising demand for fresh food, vertical farming has arisen as a viable alternative. This technology employs modern hydroponic systems to grow plants in nutrient-rich water solutions, removing the need for soil while maximizing water and nutrient utilization [8]. Vertical hydroponic farming increases sustainability by reducing resources, water, and energy use. The combination of automation and data-driven monitoring increases efficiency and production. Vertical hydroponic farming is expected to have a significant role in determining the future of food production.

Hydroponics farming is one of the focuses of the study, and adapting this technology to vertical farming has many problems that are faced by the farmers due to their limited resources of technology and knowledge on how to build their own vertical farming in hydroponics.

However, building a new system for vertical farming to produce crops is not easy due to the need to first identify the different IoT devices, sensors, and system features to monitor the hydroponics farming through mobile devices. This study aims to design a mobile-based monitoring system that constantly monitors the temperature, humidity, and water level with the integration of the Node-Re.

II. Related Literature

Hydroponics, sometimes known as controlled environment agriculture [9], is a farming system that relies on water solutions to produce crops without soil. This research presents an IoT-based hydroponic system for monitoring and controlling pH, TDS, temperature, humidity, and illumination in a greenhouse. The system employs seven sensors, six actuators, and a mobile application to provide real-time monitoring of environmental and nutritional data. The technique, which has been tested on coriander, minimizes human work while also promoting chemical and pesticide-free crops.

This study will investigate the use of life cycle assessment (LCA) to evaluate the environmental effect of protected agriculture [10]. It analyzes scientific productivity trends and research opportunities, follows the historical track of agricultural LCA, and examines environmentally friendly techniques. The study emphasizes the context-dependent environmental advantages of protected agriculture, particularly in areas with harsh weather, and recommends using circular bioeconomy solutions to reduce these trade-offs. The findings give a qualitative interpretation of the LCA findings.

This study discusses hydroponics, a soilless cultivation method, and compares it to conventional agriculture [11]. It assesses the environmental effect, water and energy use, and agricultural contamination. Case studies include tomato and cannabis growing. Hydroponics has several advantages, including zero-soil cultivation, land-use efficiency, and water saving. Disadvantages include costly investment prices, a need for technical expertise, and increased energy usage.

Research on lettuce cultivars discovered that the growing season and cultivars had a substantial impact on yield, biomass, and quality [12]. The nutrient solution EC treatment had a substantial influence on biomass and water content; however, the growth season and cultivar had a greater impact on green lettuce production and quality. According to the study, greenhouse production of lettuce cultivars in the southeast United States should take place in the spring.

This study looked at the use of cheese whey wastewater as a nutrient solution for tomato production in hydroponic systems [13]. The wastewater was processed with lime precipitation and natural carbonation before being irrigated through various techniques. Results revealed good quality tomato production with a high yield, with setup_A having the greatest maturity and taste indices. The reuse of cheese whey wastewater reduced freshwater use, allowing for treated final effluent, and minimized land deterioration in a circular economy approach.

However, in the proposed study, it is hydroponic farming that constantly monitors the lettuce crop using different sensors, like temperature, humidity, and water. Through the integration of Node-Red, hydroponics farming can be monitored using mobile devices.

III. Material and Methods

This section provides a detailed discussion of the methodology used in the study. Feature-Driven Development (FDD) was utilized for hardware and design development of the system for hydroponics farming, while the Design Thinking Process was specifically for providing innovative ideas and on how to collect the necessary data for the study.

A. Software Methodology

The researchers employed FDD as a software technique, whereas Jeff De Luca and Peter Coad developed FDD as a framework in Agile methodology [14]. As the name says, it focuses on developing functioning software and hardware with capabilities that fulfill the objectives of the study. The FDD has five components, such as generating a model, creating a list of features, planning out each feature, designing each feature, and building each feature.

The first part of FDD is to create a primary model and write the outline. The researchers will construct comprehensive domain models using the objectives as a guide, which will then be integrated into one overall model that serves as a basic blueprint for the system. As the project progresses and the researchers gain expertise, more details will be provided.

Fig. 1 depicts the suggested system's architectural design and how it functions in hydroponic farming. The water level sensor, the Node MCU (ES8266), the Temperature and Humidity Sensor (DHT11), and certain actuators such as the fan and water pump are all used in the design to measure the temperature, water level, and humidity in the surrounding environment.

The pH, temperature, and humidity all contribute to faster plant development and higher harvests of the highest quality [15]. When the temperature rises above the threshold, the system will turn on the cooling fan to reduce the heat. Additionally, the monitoring system [16] is also capable of detecting water levels in the container. In response to that, when the sensor detects that water is below the average level, the system will send a command to the water pump to increase the water supply in the container. The data reading will then be sent to the cloud using node-red.

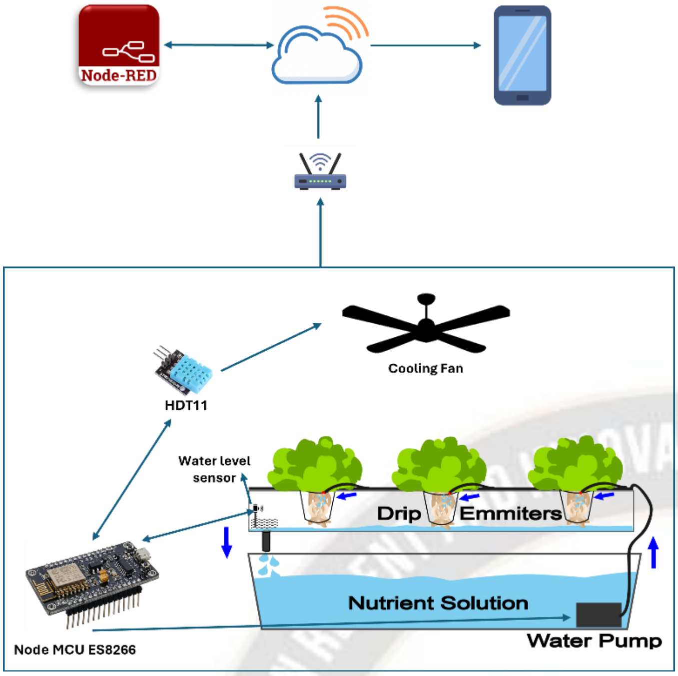

Figure 1. The architectural design of the monitoring system.

Node-RED is an open-source flow-based programming tool for visualizing event-driven applications, particularly for IoT projects [17]. The study presents an IoT application for temperature and humidity sensing on the Raspberry Pi, utilizing the DHT11 sensor and IBM Bluemix Cloud, using Raspbian Stretch Lite and Node-RED tools [18]. Node-Red is very useful to visualize, connect, and collect data from the environment using IoT devices.

Additionally, mobile phones may display data readings collected from the environment of hydroponic farming. Monitoring room temperature, pH, and water level on hydroponic plants is powered by Internet of Things (IoT) technology and runs on the Android platform. It will monitor and regulate all characteristics of a hydroponic system, including water level, pH, humidity, and temperature, via IoT.

The second phase is creating a feature list, which leverages the information from the previous step to build a list of necessary features. The next phase is to plan each feature, which involves analyzing the difficulty of each feature and planning corresponding activities for team members to execute. The researchers developed a function that may be put into a mobile device to aid hydroponic growers. The user profile and dashboard for the sensors of humidity, temperature, and water level, are among these features.

The fourth step is design by feature, in which a programmer determines which features will be created and constructed. He or she will also identify the class owners, feature teams, and feature priorities that can be implemented into the mobile device to aid hydroponic farmers. Fig. 2 shows the circuit design of the monitoring system as a guide for the development of the features mentioned above. The circuit diagram is composed of the different microcontrollers that will be used in the design of the monitoring system. These systems, using microcontrollers and sensors, allow remote monitoring and control of indoor hydroponic farming. When the circumstances are not good, the technology provides real-time warning to the hydroponic farm.

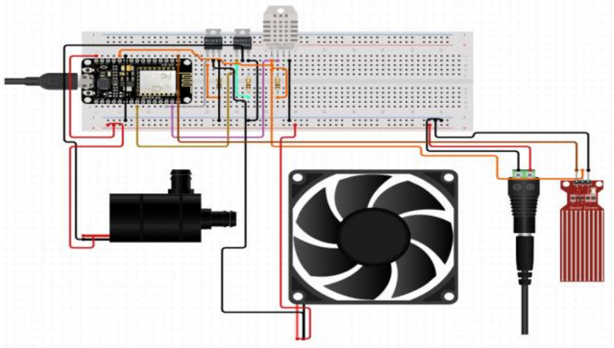

Figure 2. The circuit design of the monitoring system.

Finally, build by feature, which entails implementing all the features necessary to support the concept. User interfaces, as well as technical design components, are constructed here, as is a feature prototype. The feature can be promoted to the main build when the unit has been tested, inspected, and approved.

In this section, Fig. 3 is a flow of the smart system designs and shows how the project works if the conditions of different sensors are met. The IoT devices will automatically read the measurements of the temperature, humidity, and water level, and they will be displayed on the monitoring dashboard. However, if the conditions are not met, the measurement will also be displayed on the monitoring dashboard, and the IoT device will take some actions.

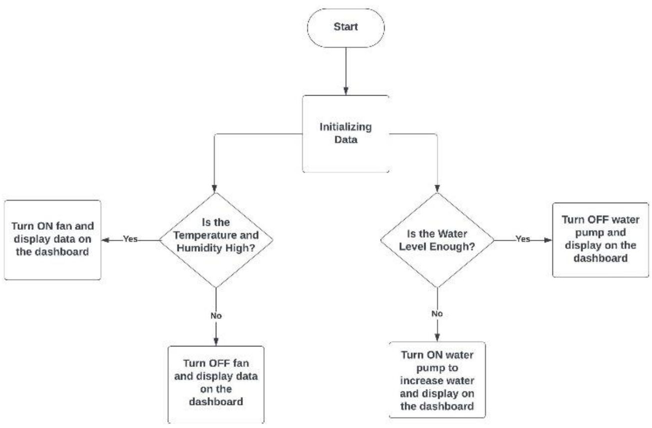

Figure 3. Flowchart of the smart system.

B. Design Thinking Process

Design Thinking Process (DTP) as shown in Fig. 4 was used to address complex problems and come up with unique solutions [19]. It was utilized in this study because it emphasizes teamwork, empathy, and innovation. It has grown in importance across a wide range of fields and sectors because of its success in stimulating innovation and human-centered design.

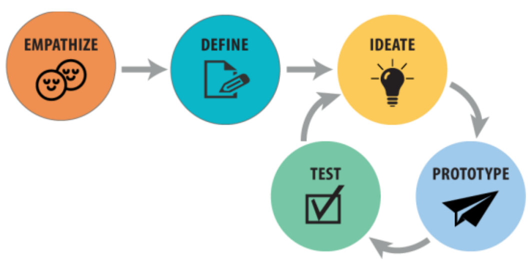

Figure 4. Design thinking process of the study.

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Empathize is the initial phase, in which the researcher begins with an expert consultation to define the needs for constructing a system prototype. In addition, the researcher examined and evaluated the materials used to create a prototype design. In addition, an interview was done to evaluate farmers' demands in terms of hydroponics cultivation. Define is the second phase, where this stage focuses on defining the issues based on the researcher's investigation, such as difficulties in determining the device's features and sensors used for hydroponic farming. The third phase is ideation, where ideation focuses on coming up with thoughts, ideas, and results as well as group brainstorming to come up with the greatest design solution, which is successfully achieved by the researchers through the sensors and IoT devices identified. The fourth one is prototyping, which is the process of developing models for an IoT device to monitor and validate hydroponic lettuce growth, as already presented in Figure 1. The objectives are to swiftly test potential ideas, initiate talks, and solve problems. Lastly, testing helps researchers discover more about the solution by getting input on the designed prototypes, which is discussed in this paper.

IV. FINDINGS AND DISCUSSION

After the researchers determined the actuators, sensors and necessary components, a graphical representation of the system design of an IoT device for hydroponic lettuce farming was presented, as shown in Fig. 5. Through this block diagram, the researchers determined the flow of the functions of each sensor from left to right as well as the response of the IoT device sensors located on the right side of the diagram. Additionally, the connectivity using a cloud successfully displayed the measurement of each sensor in terms of water level, temperature, and humidity through the dashboard on an Android or iOS device.

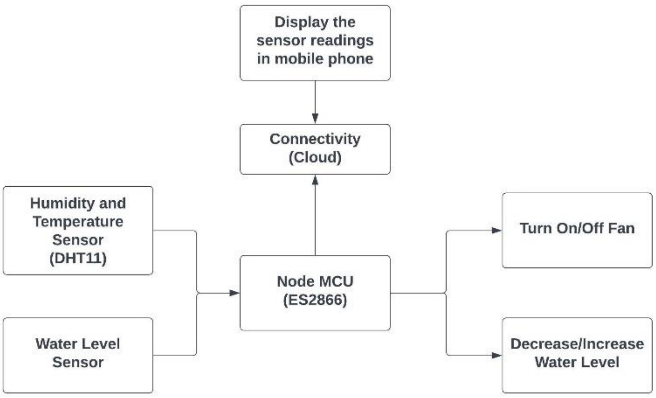

Figure 5. Block diagram of an IoT devices.

Table 1 below describes how IoT devices meet the conditions. This condition assisted the researchers as well as the system in providing the right response to the IoT device. The tolerable temperature for the lettuce crop is less than or equal to 20°C. If the temperature detected exceeds 20 °C, the system will turn on the fan to cool down the temperature.

However, humidity tolerance allows for the short-term storage of lettuce crops for 7 days. The normal humidity for short-term storage is less than or equal to 10°C. If the humidity detected exceeds 10°C, the system will turn on the fan. Lastly, the water level percentage. The normal level for water is less than 50%. If the detected percentage is higher than normal, the system will drain the excess water to achieve the right amount.

TABLE I. SENSOR'S CONDITION AND RESPONSE TO THE SYSTEM

Sensors	Sensors Condition	System Response
Temperature tolerance	<= 20 °C	Normal
	>20 °C	Turn on fan
Humidity tolerance for short-term storage of 7 days	<= 7 – 10 °C	Normal
	> 10 °C	Turn on fan
Temperature tolerance	<50 %	Normal
	>50 %	Water will drain

Furthermore, Fig. 6 shows the dashboard for water level, temperature, and humidity sensors. The dashboard illustrates the counts of measurements of the water level, humidity, and temperature. Additionally, the data readings of the temperature and humidity sensors, as well as the water level sensor, can be viewed through integrated features on mobile devices.

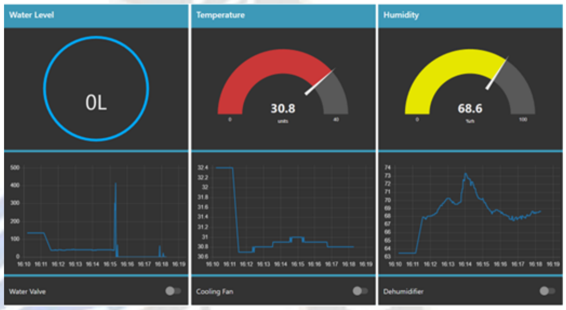

Figure 6. Dashboard of the smart monitoring system (water level, temperature, and humidity).

As long as the Android or iOS devices are connected to the internet, smart hydroponics lettuce farming may continually monitor the lettuce crop from anywhere. This could benefit farmers who want to build their own small or large hydroponic farm. This kind of cultivation is very popular all over the world and supports the hunger of individual people. Based on the analysis of the researchers, many articles stated that vertical farming has made a big contribution to agriculture. With the support of the governments of each country, small or large companies can provide a huge supply of different crops made in vertical farming. Using different sensors and IoT devices helps the agricultural industry innovate the production of crops. Vertical farming is also continuing to spread, even though, here in the Philippines, many researchers' studies on how to improve and innovate the production of crops have been conducted.

However, the significance of this study to others is the use of mobile devices and Node-Red. The data gathered by the sensors and, with the help of IoT devices, the collected data from the surroundings of lettuce crops were transferred to the Node-Red dashboard with the help of the cloud and viewable on mobile devices. With integrated features, such as a user profile and a dashboard for the sensor, such as humidity, temperature, and water level, with controls, it is easy to navigate the condition of lettuce crops. However, the study was limited to the use of the internet or data connection for constantly viewing and monitoring the dashboard of water level, humidity, and temperature of the surroundings for the lettuce crops.

V. CONCLUSION

The main goal of this research is to create a design for hydroponic lettuce cultivation. Thanks to the data that the researchers gathered, Fig. 2 is the circuit-designed system developed by the researchers that fulfilled the aims of the study. Furthermore, Fig. 1 shows the completed designs for how hydroponic lettuce farming is monitored. Additionally, the researchers used different methods as a guide for the study. After the development of the study, Fig. 5 revealed the monitoring dashboard for a hydroponics lettuce farm with useful data. The researchers also found out that the use of these IoT devices with integration of Node-Red can easily monitor hydroponic lettuce farming, which will benefit many farmers who adapt vertical farming. However, several challenges are faced by the researcher, such as the materials to be used in monitoring the hydroponics farm, the design, and the concept of how to transfer the data from censors to a mobile device. Due to the challenges faced during the development of the proposed study, the researchers suggested exploring more about Node-Red and other possible uses of it in the IoT.

ACKNOWLEDGMENT

The authors would like to thank the University of the Cordilleras, where the researchers were affiliated. Special thanks to CHEDRO5-SIKAP Grants for their support in this study.

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